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TRANSIENT PERFORMANCE OF QUARTZDYNE® PRESSURE TRANSDUCERS

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ABSTRACT

This report describes the transient performance of Quartzdyne® Pressure Transducers, including preliminary results of a new ¾" SXP transducer projected for release later this year. Transient pressure errors are those brief errors measured during, or shortly after, a pressure and/or temperature change. These pressure and temperature changes may take place as rapid step changes, or as gradual (ramping) changes. Since "transient" means brief, these momentary errors disappear once the transducer reaches equilibrium at a stable pressure and temperature. Minimizing both the amplitude and the duration of these transient errors allows our customers to construct highly accurate tools for reservoir analysis and pump monitoring systems.

INTRODUCTION

All Quartzdyne® Pressure Transducers have three quartz crystals: a pressure-sensing crystal, a temperature-sensing crystal, and a reference frequency crystal. Each transducer model has a different transient response, due to the packaging variations of the three quartz crystals. During the calibration of each transducer, we maintain the oil bath temperature to 0.01°C, thus establishing a stable thermal coupling between the pressure, temperature, and reference crystals. After making any pressure or temperature change, several minutes are allowed to pass in order to restore thermal equilibrium between the three crystals.

Transient errors occur when any of the three quartz crystals is out of thermal phase with the other two crystals. Large pressure steps (100s of psi) produce changes in fluid temperature due to the adiabatic work performed in compressing the fluid. This is commonly referred to as PV heating. External temperature changes (temperature ramps or plunges) also disturb the thermal equilibrium of the transducer. Regardless of the source of the temperature change, there will be a transient error in the pressure reading until the three quartz crystals return to thermal equilibrium.

The pressure sensor has been designed to minimize transient errors in downhole work. Since the downhole environment generally follows the trend of simultaneously increasing pressure and temperature with depth, we chose the crystallographic orientation of the quartz pressure sensor to provide optimum behavior along the "zero" line (0 psi/°C) shown in Figure 1.

To explain the curves of Figure 1, consider a transient event that generates an instantaneous 1°C temperature difference (ΔT) between the pressure and temperature crystals. If the event takes place on the "±5 psi/°C" line, a transient error of ±5 psi will occur. Similarly, a 1°C ΔT occurring on the "±10 psi/°C" line would produce a transient error of 10 psi. If the transducer is used in the pressure and temperature ranges between the two "±5 psi/°C" lines of Figure 1, the transient errors are small. At test pressures and temperatures approaching the "zero" line, the transient errors are nearly zero. Since extremes (low temperature at high pressure and high temperature at low pressures) are rarely experienced downhole, large transient errors will not occur in most downhole work. Please note that Quartzdyne® Pressure Transducers vary individually; however, the lines of Figure 1 are typical.

The magnitude of the transient pressure error is a function of (1) the magnitude of the thermal event (external temperature change or PV heating), **and** (2) the final pressure and temperature. The **optimum** transient performance will be obtained along the "zero" line of Figure 1. On the "zero" line, the pressure sensor has minimal thermal sensitivity, which reduces the precision of temperature measurement required for its thermal compensation. For this reason, pressure or temperature transient events that occur near the "zero" line will show little transient error. (Note that the ending P-T point is important in Figure 1; the starting P-T point is not a factor.)

The time required for an error to decay is a function of the thermal system, including the transducer, the downhole tool, and the wellbore fluid. The equilibration time observed in our tests of bare transducers in a liquid bath is typically 3-4 minutes. Liquid plunge tests (from 25°C to 140°C, for example) produce much larger temperature effects, but the resulting pressure errors equilibrate within a few minutes.

EXPERIMENTAL DETAILS

As noted, a temperature difference between the pressure sensor and the temperature sensor can be produced by pressure steps, or by external temperature events, such as temperature ramps or plunges. We have performed a number of transient tests to provide general indications of downhole performance. Since our tests have examined bare transducers in a liquid bath, they only approximate performance of a complete downhole tool, except for the Series SXP, which is designed to form part of the exterior wall of the downhole tool.

We tested four transducer variations, each described below. Refer to Figure 2, which illustrates the differences between models. All transducers were tested with bellows fitted to the transducer, Tests have shown that the presence or absence of bellows does not affect the accuracy or transient performance of any Quartzdyne® Pressure Transducer, except below pressures of 50 psi.

QH	This 1-inch model was modified in 1999 to improve the thermal coupling between the pressure crystal and the surrounding metal housing. The improvement also reduced the oil volume surrounding the pressure crystal, minimizing the amount of energy generated during a PV event. Furthermore, the energy dissipates quicker due to the improved heat transfer between the pressure crystal and the surrounding metal.
QM	This model is similar to the 1-inch QH, but has a reduced diameter of 7/8 inch.
Old SXP	This ¾" model locates the temperature and reference crystals into a carrier about two inches away from the pressure crystal: they did not fit into the pressure bulkhead.
New SXP	A redesign of the old SXP, allowing us to place the temperature and reference crystals into the pressure bulkhead and much closer to the pressure crystal.

Unless noted otherwise, these transient tests were performed simultaneously, with all four transducers on a single pressure manifold. A DH Instruments Deadweight Tester maintained pressure, while the external temperature of the transducers was controlled by an 18" deep Hart Scientific stirred liquid bath, stable and uniform within 0.01°C. The table lists the figures containing the transient results:

Figure Number	Event Type	Starting Conditions		Ending Conditions	
		Pressure	Temperature	Pressure	Temperature
3	P_{drop}	5 kpsi (344 bar)	104°F (40°C)	0 psig (1 bar)	104°F (40°C)
4	P_{drop}	5 kpsi (344 bar)	347°F (175°C)	0 psig (1 bar)	347°F (175°C)
5	T_{ramp}	2 kpsi (138 bar)	104°F (40°C)	2 kpsi (138 bar)	140°F (60°C)
6	T_{ramp}	2 kpsi (138 bar)	284°F (140°C)	2 kpsi (138 bar)	350°F (177°C)
7 & 8	T_{step}	0 psig (1 bar)	77°F (25°C)	0 psig (1 bar)	284°F (140°C)

DISCUSSION OF RESULTS

We choose pressure drops from 5 kpsi to atmospheric pressure for two reasons. First, venting pressure to atmospheric is an effective means of generating an instantaneous pressure event. Second, venting to atmospheric pressure creates significant (worst case) adiabatic cooling since the oil is most compressible at low (<100 psi) pressures. In contrast, generating a pressure step with a deadweight tester is slow and requires manual control. (For example, generating a pressure step from 12 kpsi to 16 kpsi requires roughly 20 seconds to advance the screwpress. Most of the adiabatic (PV) heating has dissipated by the time 16 kpsi is reached.)

Figure 3 illustrates a PV-event taking place at low pressure and low temperature (LPLT). Since the PV event takes place close to the "zero" line, all four transducers have remarkable transient performance.

In Figure 4, the same pressure drop is repeated at high temperature (LPHT). Since the pressure crystal has higher temperature sensitivity at LPHT, the transient errors are more pronounced. Note the temperature crystal placement in the new SXP improved its transient correction. (Historical note: pre-1999 Quartzdyne® Pressure Transducers exhibited 20-psi errors, and required 5 minutes to recover.)

Figures 5 and 6 demonstrate each transducer's response to gradual changes in external temperature. Since the temperature ramp of Figure 5 takes place close to the "zero" line, the transient errors of each transducer design remained within a few psi of the original values. The high temperature ramp shown in Figure 6 is further from the "zero" line, but the errors remained reasonable due to the slower rate of change. (The temperature ramp rates in both tests were different, due to the maximum heating rate of the fluid bath. Increased ramp rates will produce larger errors.) The old SXP appears to perform best in Figure 6; the de-coupled placement of the temperature crystal in the old SXP causes it to lag at nearly the same rate as the pressure crystal. In all other models, the temperature crystal responds faster than the pressure crystal to temperature changes.

Figures 7 and 8 demonstrate the response of individual transducers when subjected to a rapid step change in external temperature. The transducers were quickly lowered into a 140°C bath, causing significant errors during the thermal disruption. Note that the new SXP has the quickest temperature response due to its small diameter and intimate coupling between the temperature crystal and the fluid-wetted pressure bulkhead.

It should be noted that all of these tests were conducted with the transducers immersed in a liquid bath. Since this can be the exact configuration of the SXP transducer in downhole use (i.e., a ¾" memory tool), the SXP should exhibit similar performance in the field as shown in our tests. Other configurations housed inside a larger diameter pressure housing will create a thermal lag altering the response behavior of the transducer. In general, a transducer within a housing will take longer to reach thermal equilibrium after a change in pressure or temperature, but the peak amplitude of any transient pressure error should also be smaller. Testing the users' exact tool configuration will be necessary to determine the final transient behavior.

CONCLUSIONS

Since 1999, we have made significant transient response improvements to our 1-inch transducers. Most important, however, is the achievement of the new ¾" SXP. The old SXP has a built-in compromise—a large physical distance between the pressure and temperature crystals. The new SXP removes this handicap, allowing for next generation tool designs. (Unfortunately, we cannot upgrade old SXPs to the "new" style.)

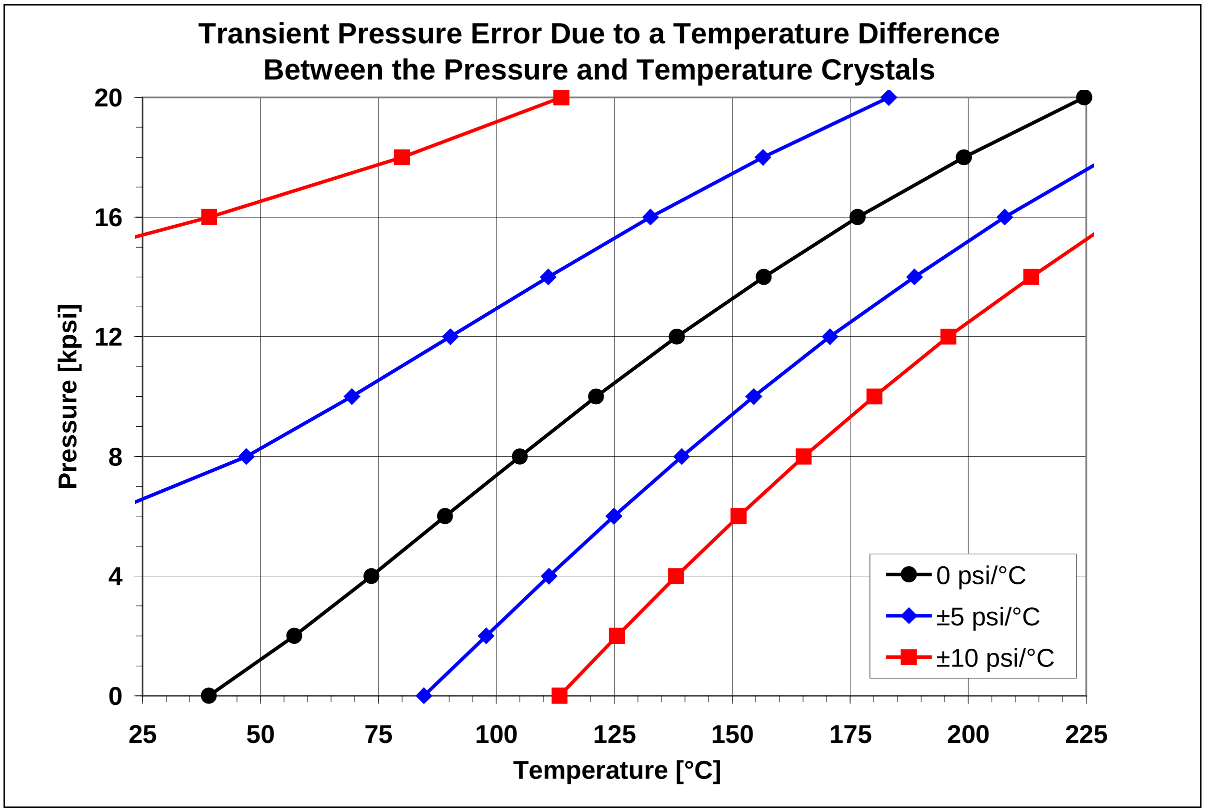

Figure 1

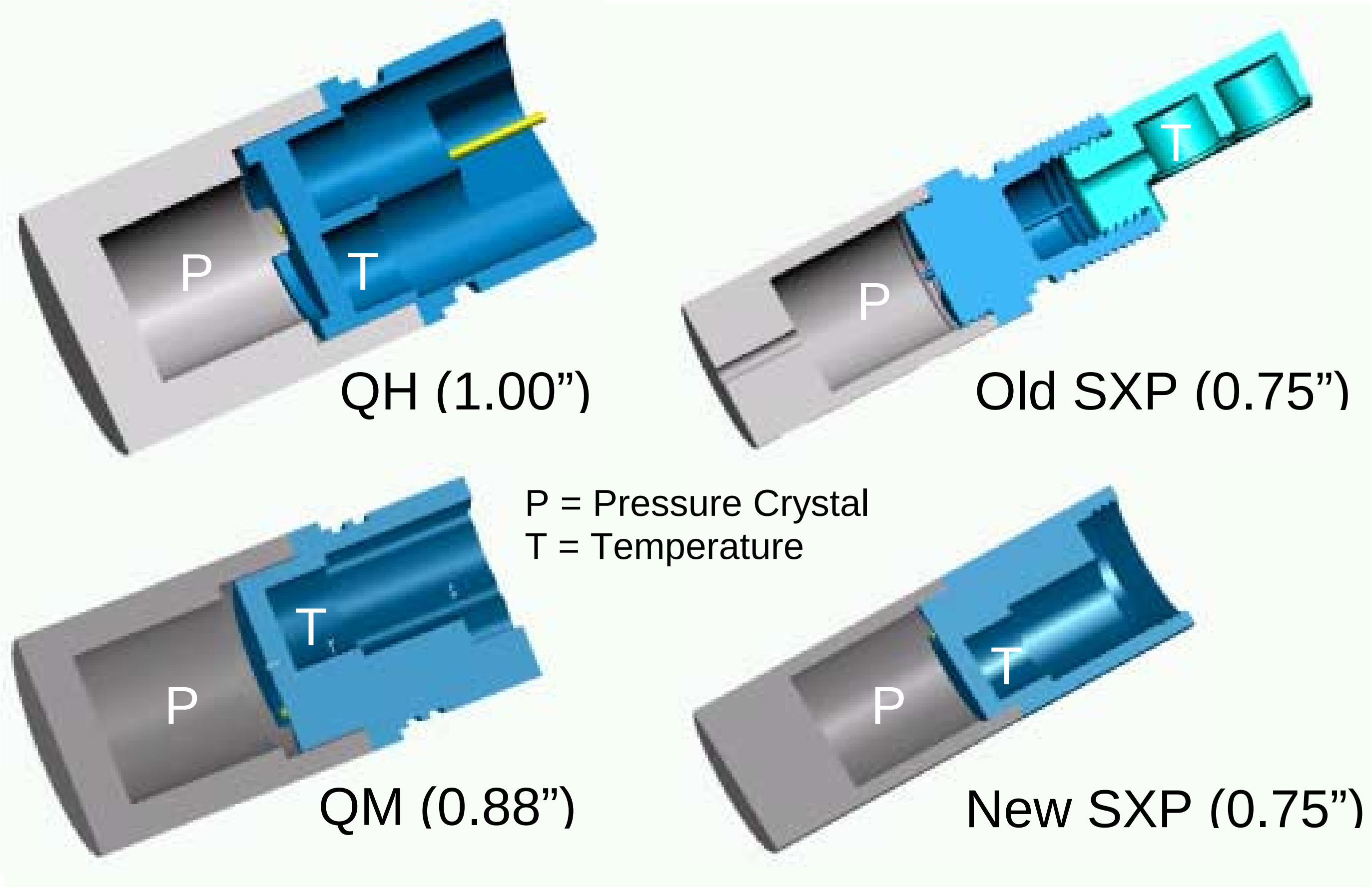

Figure 2: Cross-Section of Quartzdyne® Pressure Housings

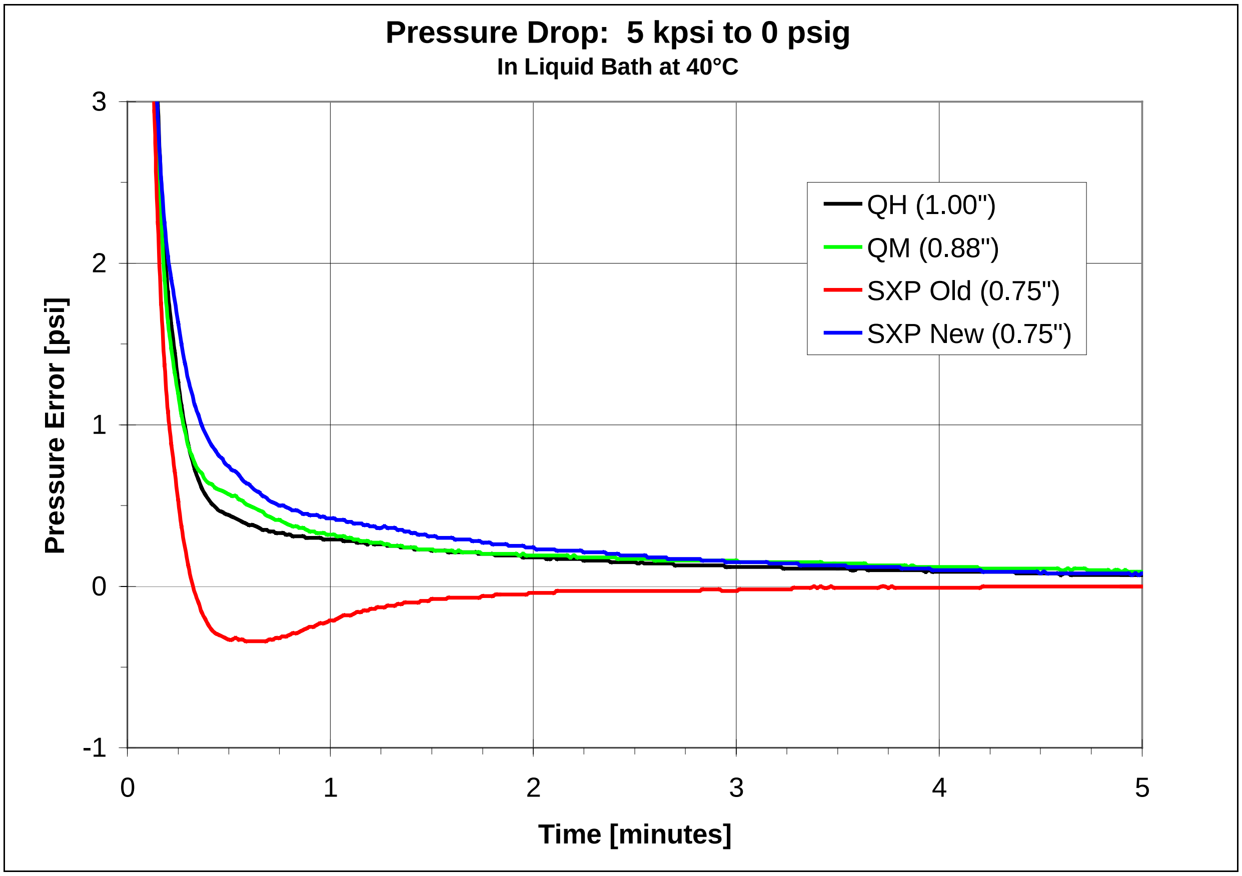

Figure 3

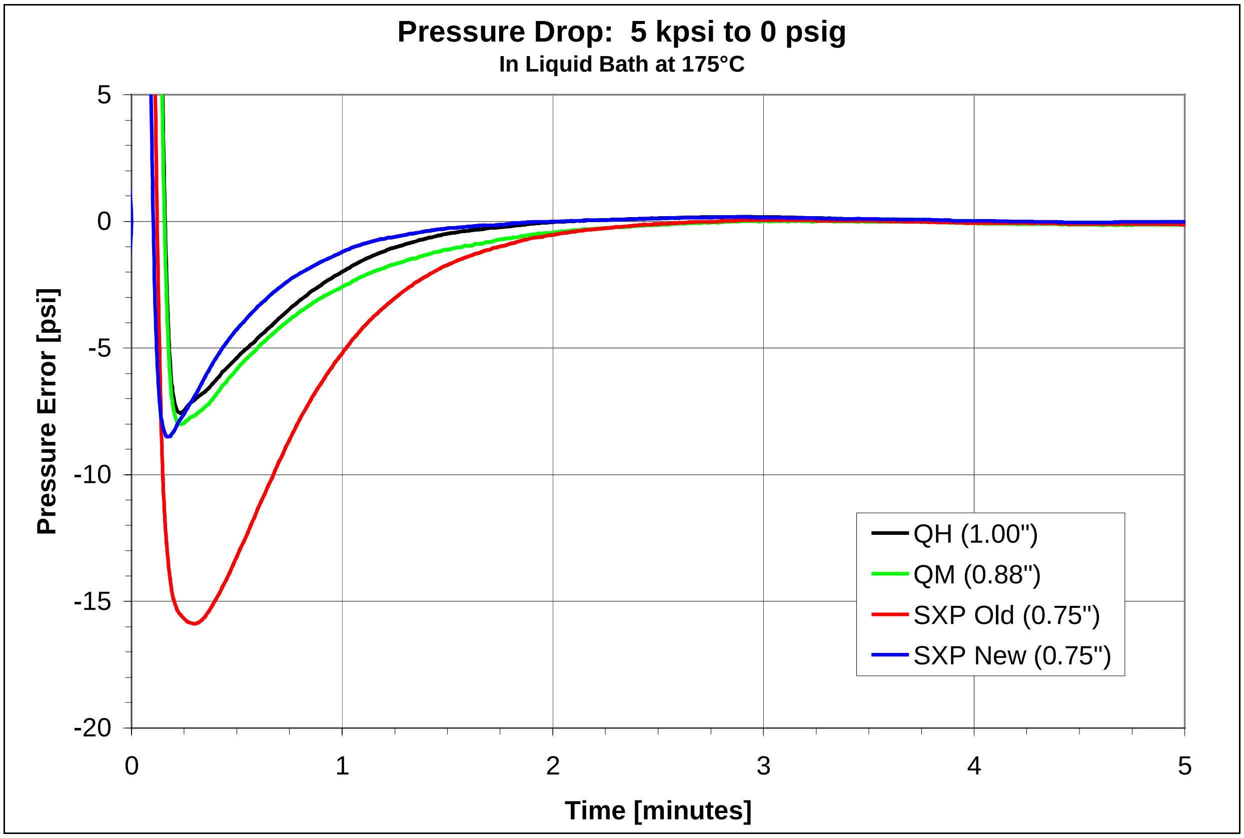

Figure 4

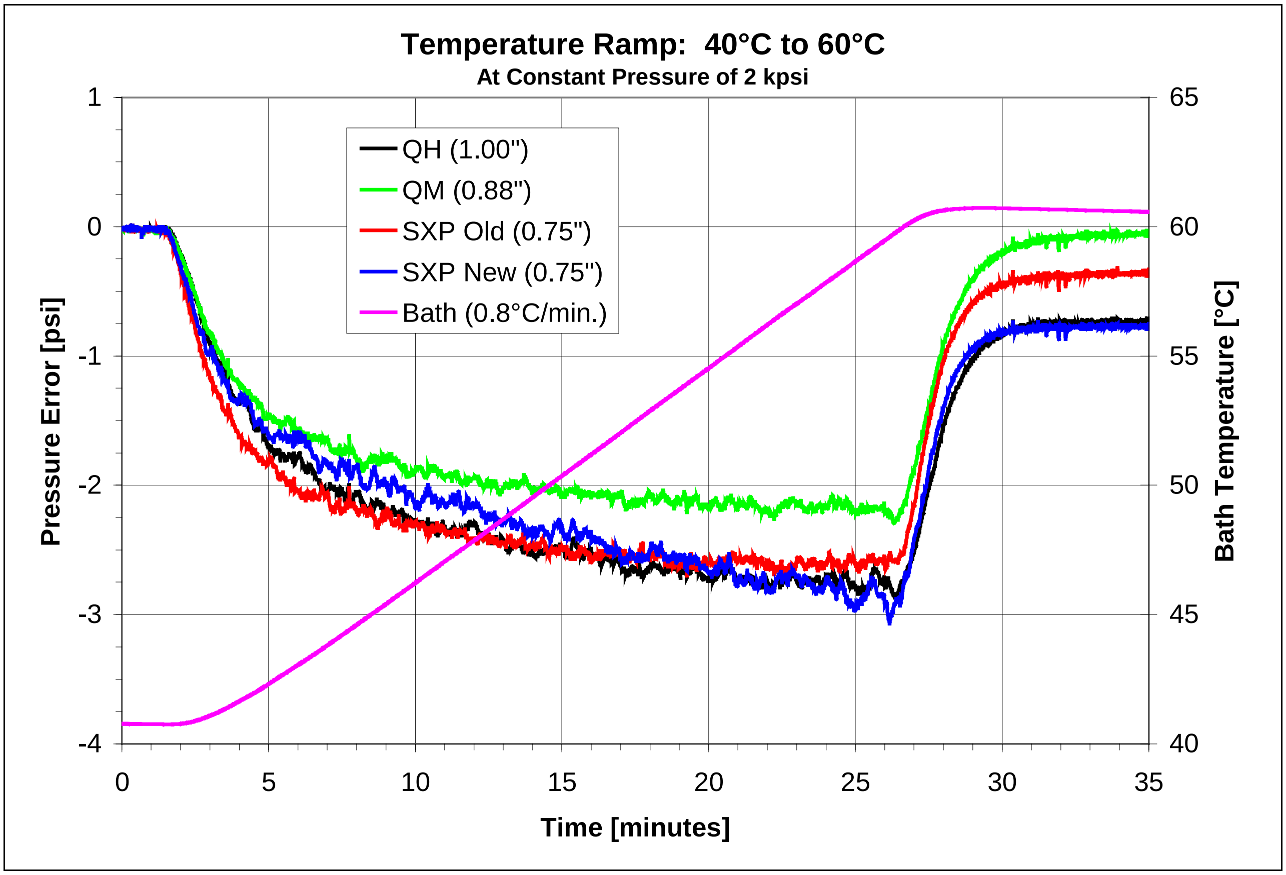

Figure 5

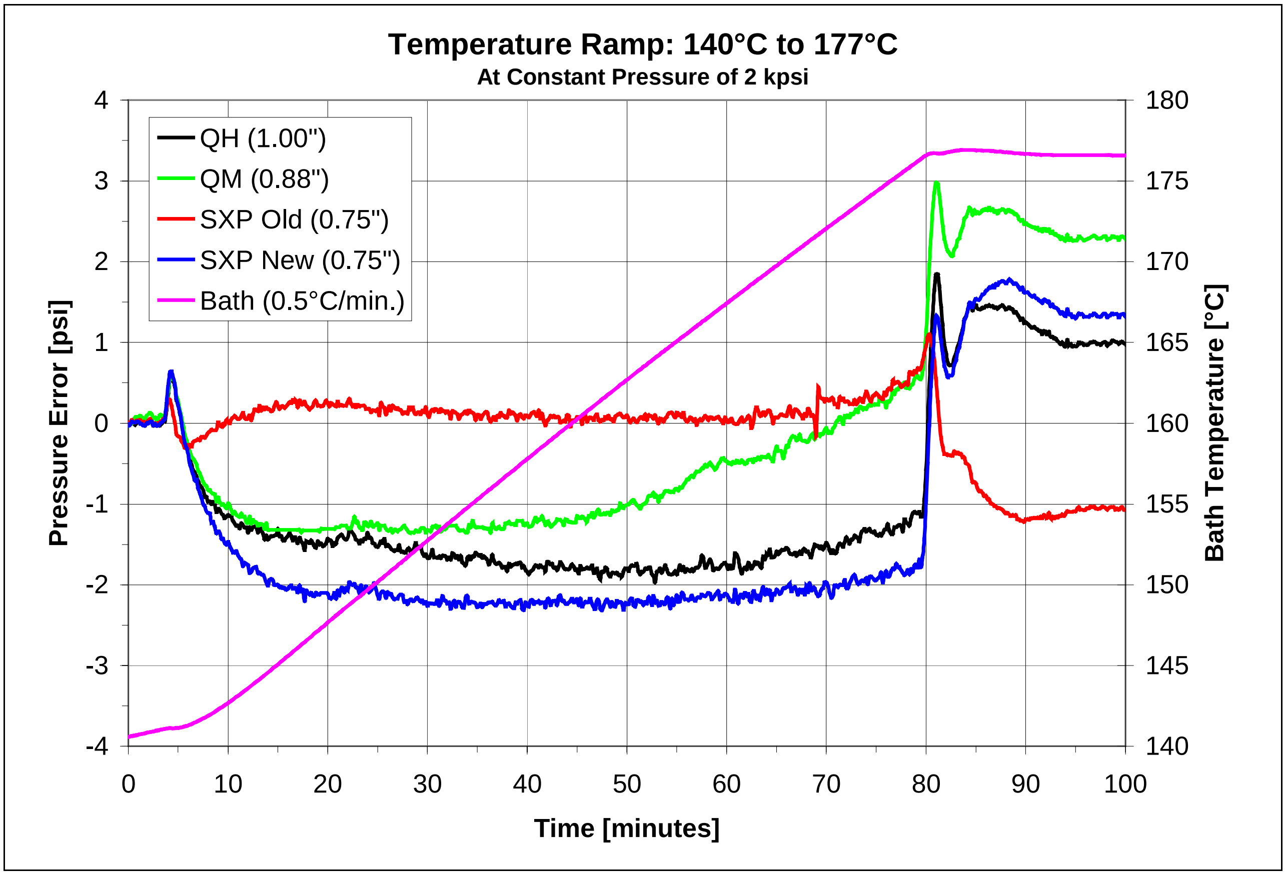

Figure 6

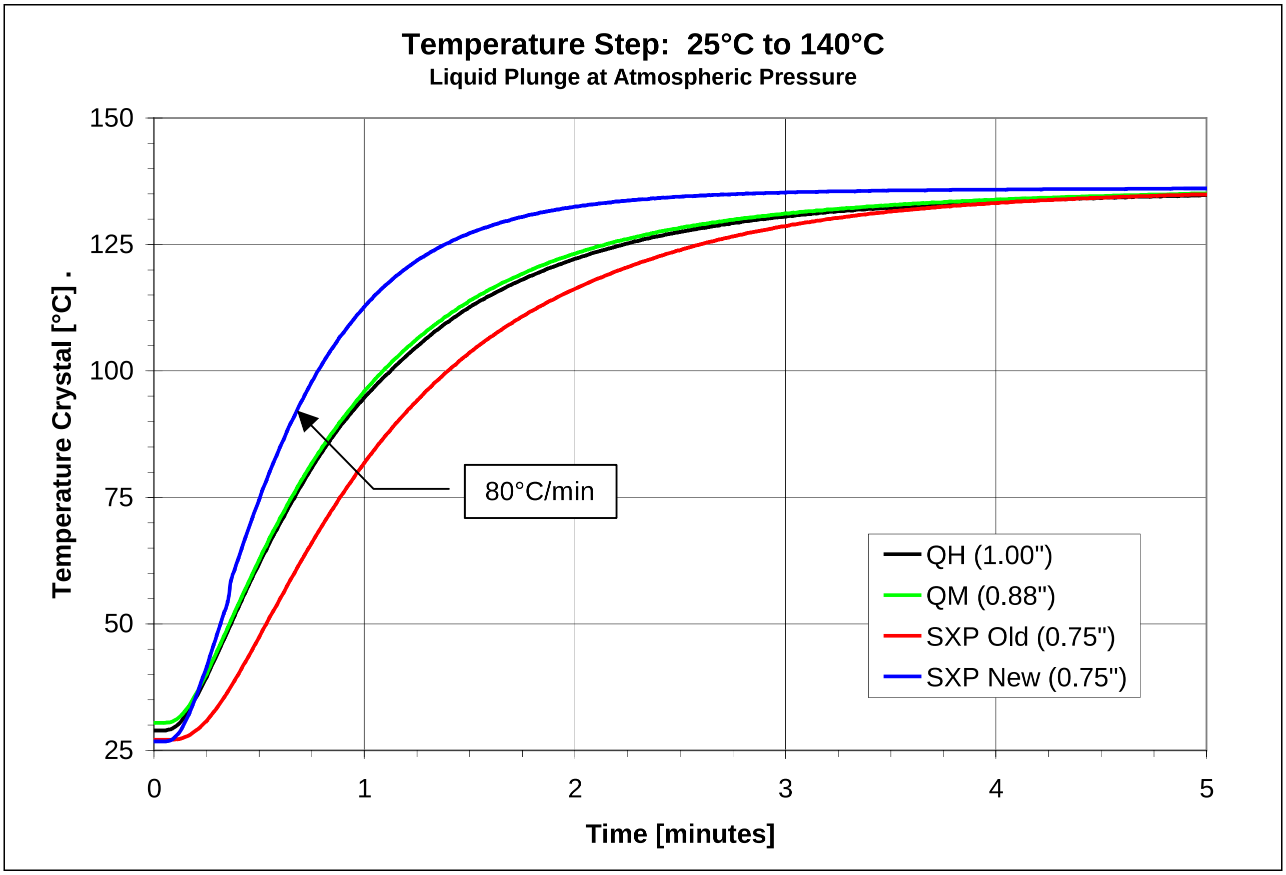

Figure 7

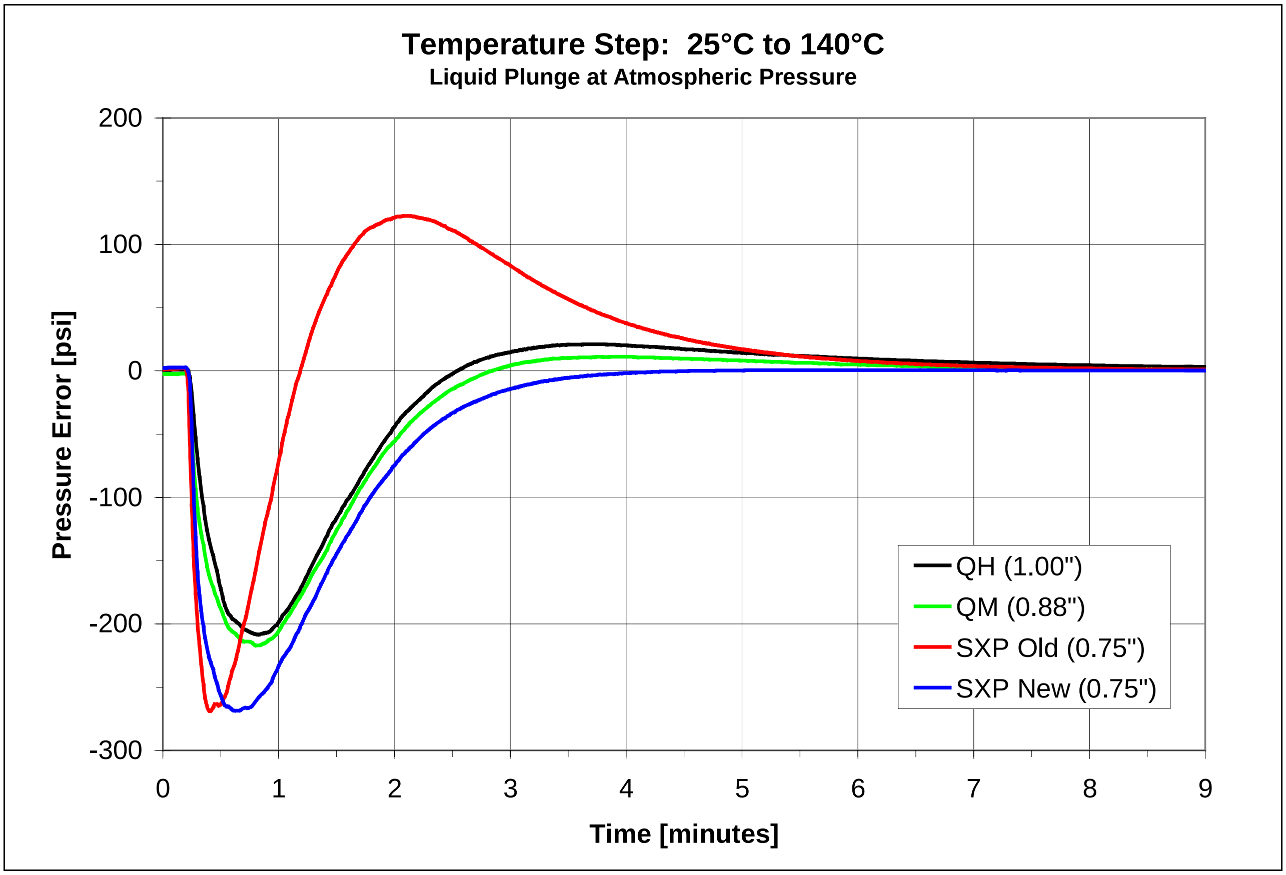

Figure 8